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and Space Administration

Scientific and Technical
Information Branch

Summary

An investigation was conducted to examine the effects of a moist nitrogen environment on the friction and deformation behavior of magnetic tape in contact with a nickel–zinc ferrite spherical pin. Friction experiments were conducted with loads of 0.25 and 0.5 N at a sliding velocity of 0.1 mm/sec with a total sliding distance of 10 mm for both single-pass and multipass sliding. Experiments were performed in nitrogen at relative humidities to 78 percent at 23° C. Multipass sliding experiments in reciprocating motion were conducted.

The coefficient of friction is strongly dependent on the ambient relative humidity. Although the coefficient of friction remains low below 40-percent relative humidity, it increases rapidly with increasing relative humidity above 40 percent. The general ambient environment of the tape does not affect the friction behavior if the area where tape is in contact with the ferrite pin is flooded with controlled nitrogen. The response time for the friction of the tape to humidity changes is about 10 sec. The friction response during dehumidifying is very similar to that during the humidifying process. A surface softening of the tape due to water vapor increases the friction for the tape.

Introduction

Magnetic tapes normally use γ–Fe_2O_3 or CrO_2 powder held in a nonmetallic binder. Composed largely of oxide particles, the magnetic layer bears a certain resemblance to emery, a familiar abrasive. For example, the abrasiveness of a magnetic tape containing 0.7-μm ferric oxide (γ–Fe_2O_3) was almost the same as lapping tape, which contains 1.5-μm silicon carbide abrasive (mesh no. 6000) impregnated tape (ref. 1). Carroll and Gotham observed that ambient relative humidity has a marked effect on the abrasiveness of tapes with tape abrasiveness rising with increasing humidity (ref. 2). They briefly stated that (1) the friction of tape is dependent on humidity, and (2) the moisture content or humidity conditioning of the tape is of negligible importance if the area where the tape contacts the surface is flooded with dry air. They did not, however, present any data to support these statements.

This investigation examines the effect of humidity in moist nitrogen on the friction and deformation behavior of magnetic tape in sliding contact with a nickel-zinc ferrite pin. The sliding friction experiments were conducted with loads of 0.25 and 0.5 N at a sliding velocity of 0.1 mm/sec with a total sliding distance of 10 mm in single-pass and multipass sliding, in nitrogen at relative humidities to 78 percent, and at 23° C. Multipass sliding experiments were conducted in reciprocating motion.

Materials

The magnetic tapes used in this investigation contained CrO_2 powders coated on a polyester film backing (thickness, 23 μm; film width, 12.7 mm). Magnetic tape consists of a layer structure, as shown in figure 1. The composition and data of surface roughness and Knoop hardness are presented in table I.

The hot pressed polycrystalline nickel-zinc ferrite (Fe_2O_3, 66.6 wt%; NiO, 11.1 wt%; ZnO, 22.2 wt%) is a ceramic semiconductor. The grain size of the nickel-zinc ferrite was about 8 μm (ref. 3). The porosity of the polycrystalline ferrite was less than 0.1 percent.

Apparatus

The apparatus used in this investigation is shown schematically in figure 2. It was basically a pin (rider) on a flat. The magnetic tapes (12.7 mm wide and 30 mm long) were mounted on hardened steel flats and retained in a vice mounted on a screw-driven platform. The platform was driven through the screw by an electric motor with a gear box that allowed for changing the sliding velocity. Motion was reciprocal. The pin was made to travel 10 mm on the surface of the tape. A switch then reversed the direction of motion so that the pin retraced the original track from the opposite direction. This process was repeated continuously.

The ferrite pin was loaded against the magnetic tape with deadweights. The arm retaining the pin contained strain gages to measure the tangential and normal forces. The arm containing the pin could be moved normal to the direction of the wear tracks. Thus, multiple tracks could be generated on a single surface. The entire apparatus was housed in a plastic box. The atmosphere in the box was controlled in two ways.

The first was one in which the entire plastic box was filled with dry or humid nitrogen, as indicated in figure 3(a). The second was that in which dry or humid nitrogen was admitted locally through a nozzle onto the tape surfaces, in contact with the pin specimens, as shown in figure 3(b).

Experimental Procedure

The nickel–zinc ferrite hemispherical pin specimen was polished with a diamond powder (particle diameter, 3 μm) and with an aluminum oxide (Al_2O_3) powder (1 μm).

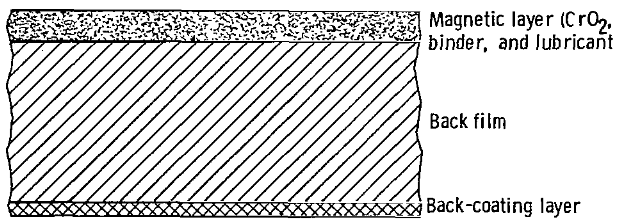


Figure 1. – Schematic of magnetic tape.

The radius of the pin was 2 mm. The pin surface was rinsed with 200-proof ethyl alcohol.

Humidity Effect on Friction

After the system shown in figure 3(a) was conditioned to a desired humidity, a polished nickel-zinc ferrite pin and a new as-received tape were placed in the experimental apparatus. Single-pass sliding friction experiments were conducted with the same magnetic tape, but on different tracks, in contact with the nickel-zinc ferrite pin in the desired environment at a load of 0.5 N. In each experiment, the pin specimen was replaced with a new repolished pin.

Single-pass sliding friction experiments at a load of 0.25 N were then conducted with the same magnetic tape, but on different tracks, in contact with a new repolished pin in the desired environment. Thus, a tape was used only in a desired environment; a new as-received tape was used for each environmental condition. Each value of the coefficient of friction is the average of measurement obtained from three to five single-pass sliding experiments.

Deformation of Tape

Multipass sliding friction experiments were conducted with the magnetic tape in contact with nickel-zinc ferrite pins in dry nitrogen and in humid nitrogen at a relative humidity of 78 percent. In each experiment, the new ferrite pin traveled and retraced the original tracks on the tape.

Reversibility of Friction on Humidifying and Dehumidifying

After admitting dry nitrogen gas into the system shown in figure 3(a), a polished nickel-zinc ferrite pin and a new as-received tape were placed in the experimental apparatus. Single-pass sliding friction experiments were conducted with the same magnetic tape, but on different tracks, at loads of 0.25 and 0.5 N in a dry nitrogen

TABLE I. – COMPOSITION AND PROPERTIES OF MAGNETIC TAPE

Magnetic particle	CrO_2
Particle loading[a]:	
Particle by volume	50
Particle by weight	80
Binder	25-Percent nitrocellulose, balance polyester-polyurethane (32-percent polyurethane hard segment)
Lubricant	Fatty acid ester
Base film	Polyethylene terephthalate
Surface roughness[b], nm	27.3
Knoop hardness[c] at 13° C, MPa	178

[a]Magnetic particle concentration.
[b]Root mean square roughness.
[c]Measuring load of hardness, 0.0013 N.

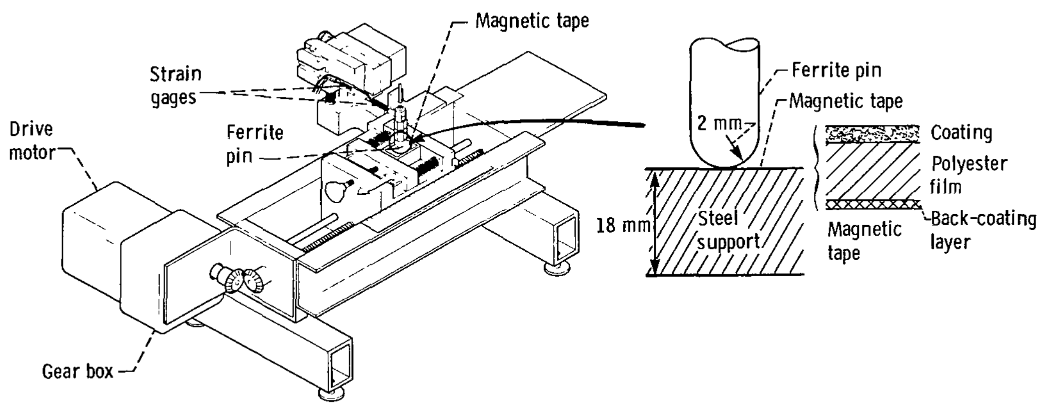
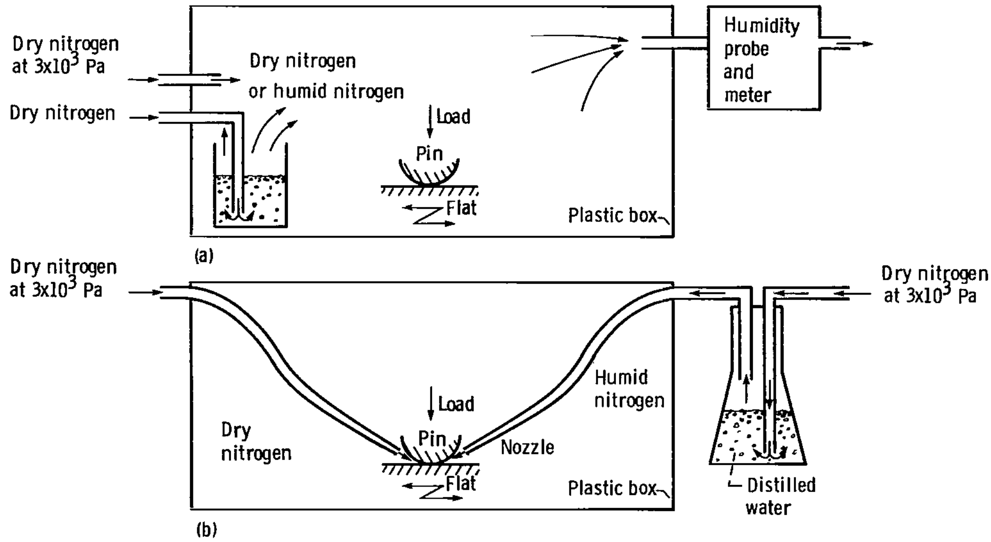


Figure 2. – Friction and wear apparatus.



(a) Controlled atmosphere.
(b) Locally controlled atmosphere.

Figure 3. – Environmental modification of friction and wear apparatus.

atmosphere. The atmosphere was then humidified to the desired humidity to 78 percent by admitting humid nitrogen into the system.

After the experiments in nitrogen at relative humidities to 78 percent, the system was gradually dehumidified to a dry nitrogen atmosphere. Single-pass sliding experiments were conducted with the same tape, but on different tracks, in the desired atmosphere during the dehumidifying processes. A new repolished ferrite pin was always used in each sliding experiment. Each value for the coefficient of friction is the average of measurements obtained from three to five single-pass sliding experiments.

Frictional Response to Humidity Changes

Three sets of environmental conditions and experiments were conducted. In the first set, a tape was preconditioned in dry nitrogen in the plastic box shown in figure 3(b) and maintained at that condition during the entire sliding friction experiment. After sliding for about 40 sec in dry nitrogen, the area where the tape contacts the ferrite pin was flooded with humid nitrogen having a relative humidity of 61 percent; but, a dry nitrogen atmosphere was maintained in the plastic box. The area flooded with humid nitrogen included less than 100 mm^2 of tape. Multipass sliding friction experiments were also conducted in the same manner as those in the single-pass sliding.

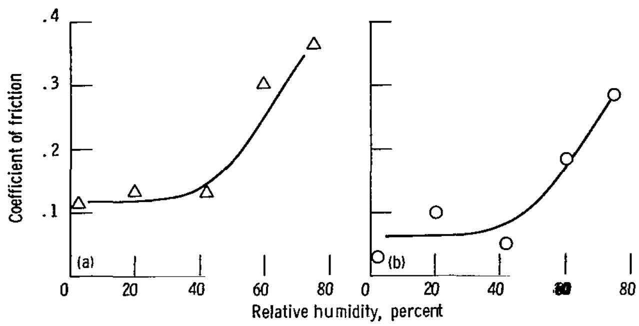
In the second set, a tape was preconditioned with 63-percent relative humidity in the plastic box shown in figure 3(b) and maintained at that condition during the entire sliding friction experiments. The vicinity surrounding the tape-ferrite contact was flooded with dry nitrogen after sliding for 40 sec in the humid nitrogen atmosphere. Multipass sliding friction experiments were also conducted in the same manner as those in the single-pass sliding. In the third set, a tape was placed in air at a relative humidity of 41 to 43 percent. The vicinity surrounding the tape in contact with the pin had been flooded with dry nitrogen (fig. 3(b)). At approximately 30 sec of sliding time, the supply of dry nitrogen was stopped and humid nitrogen, with a relative humidity of 61 percent, was admitted to the contacting area for about 30 sec. After admitting humid nitrogen, the supply of humid nitrogen was stopped and dry nitrogen was again allowed to flow into the contact area.

The dry and humid nitrogen gases were admitted through an inlet valve at relative pressures to 3×10^3 Pa. To obtain consistent experimental conditions (environmental and deformation), contact before sliding was maintained for 5 min. The friction experiment was then begun. The load and friction force were continuously monitored during a friction experiment. Sliding velocity was 0.1 mm/sec over a total sliding distance of 10 mm.

Results and Discussion

Humidity Effect on Friction

Single-pass sliding friction experiments were conducted with magnetic tapes in contact with polycrystalline nickel-zinc ferrite pins in dry and humid nitrogen at various relative humidities to 78 percent. The data of figure 4 indicate that the coefficient of friction is strongly dependent on the ambient relative humidity. Although



(a) Normal load, 0.5 N.
(b) Normal load, 0.25 N.

Figure 4. – *Effect of humidity on coefficient of friction of magnetic tape in sliding contact with a nickel-zinc ferrite pin. Sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.*

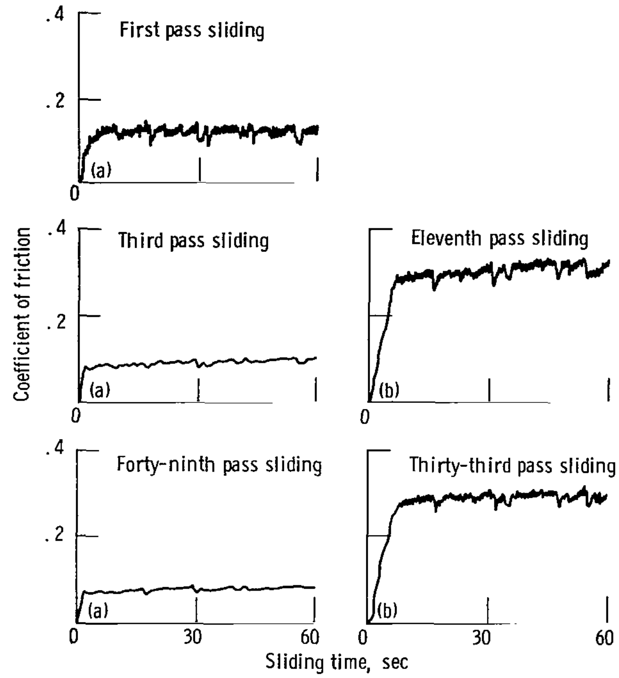
the coefficient of friction remained low below 40-percent relative humidity, it increased rapidly with increasing relative humidity above 40 percent. The trend of the results shown in figure 4 is consistent with the statement by Carroll and Gotham (ref. 2): "The tape friction rises with increasing humidity."

Deformation of Tape

It has been unknown how the interface deforms in both high humid and dry nitrogen with sliding action. The question is whether the tape can deform readily in a moist atmosphere. In order to examine the deformation behavior of the tape surface, multipass sliding friction experiments were conducted with magnetic tape in contact with polycrystalline nickel-zinc ferrite pins in both dry and humid nitrogen at a relative humidity of 78 percent.

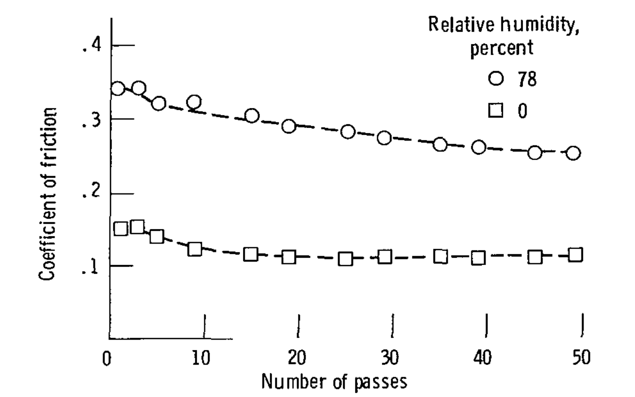
Figure 5 presents coefficient of friction as a function of sliding time resulting from sliding of nickel-zinc ferrite in contact with a magnetic tape in both dry and humid nitrogen. The traces are generally characterized by randomly fluctuating behavior with no evidence of stick-slip. In humid nitrogen a relatively large degree of fluctuating behavior in friction was observed in the first pass and in repeated pass sliding. In dry nitrogen a relatively large degree of fluctuation in friction is also observed in the first single pass of sliding. Very smooth fluctuating behavior in friction is observed with repeated pass sliding.

Figure 6 presents the coefficients of friction as a function of number of repeated passes. When 50 repeated passes are made, the coefficients of friction in nitrogen at 78-percent relative humidity are higher than those in dry nitrogen over entire numbers of repeated passes. The coefficient of friction measured in nitrogen at 78-percent relative humidity decreases slightly but continuously as the number of passes increases. On the other hand, the coefficient of friction measured in dry nitrogen is



(a) Sliding in dry nitrogen atmosphere.
(b) Sliding in humid (61 percent relative humidity) nitrogen atmosphere.

Figure 5. – Coefficient of friction as function of sliding time for magnetic tape sliding against a nickel-zinc ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C.



(a) New (as-received) tape.
(b) Wear track obtained in dry nitrogen.
(c) Wear track obtained in humid (78 percent humidity) nitrogen.

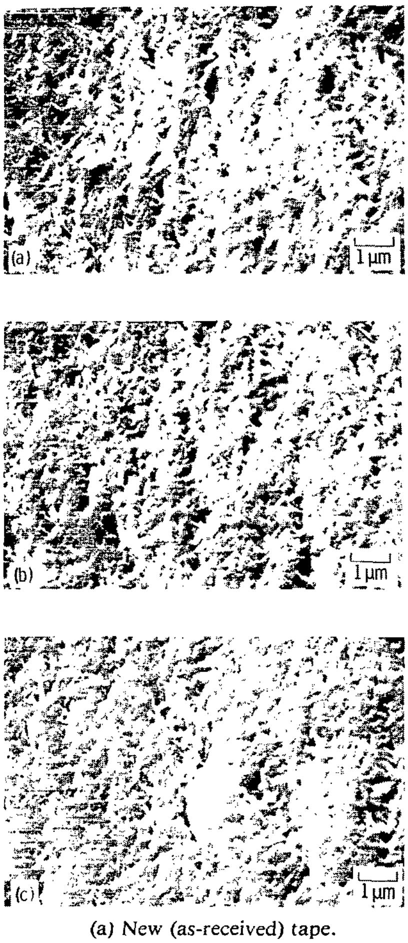
Figure 6. – Coefficient of friction as function of number of repeated passes for magnetic tape sliding against nickel-zinc ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, dry and humid nitrogen.

constant after 10 passes. It is anticipated from the results shown in figure 6 that the tape being in contact with the nickel-zinc ferrite pin in nitrogen at 78-percent relative humidity can plastically deform more than does the tape in dry nitrogen. In order to examine tape surface

deformation with sliding action in both dry and humid nitrogen, the wear tracks on the tape, where 50 repeated passes were made, were examined by scanning electron microscopy.

Figure 7 presents scanning electron micrographs of the as-received surface and wear tracks generated in dry nitrogen and in humid nitrogen at 78-percent relative humidity. The as-received surface of the tape has the coarsest structure of the surfaces shown in figures 7(a) to (c). The scanning electron micrographs shown in figures 7(b) and (c) clearly reveal a degree of plastic deformation at the tips of the asperities on the magnetic tapes.

Considerable plastic flow occurs in the tape, which was in sliding contact with nickel–zinc ferrite in the humid nitrogen at 78-percent relative humidity. It is obvious that the degree of plastic deformation of the tape sliding against nickel–zinc ferrite in the humid nitrogen is much higher than that in the dry nitrogen. The surface softening of the tape due to water vapor results in the humid nitrogen.



(a) New (as-received) tape.
(b) Wear track obtained in dry nitrogen.
(c) Wear track obtained in humid (78 percent humidity) nitrogen.

Figure 7. – Scanning electron micrographs of as-received surface and wear tracks on magnetic tape after 50 passes sliding against nickel–zinc ferrite pin. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C.

Reversibility of Friction on Humidifying and Dehumidifying

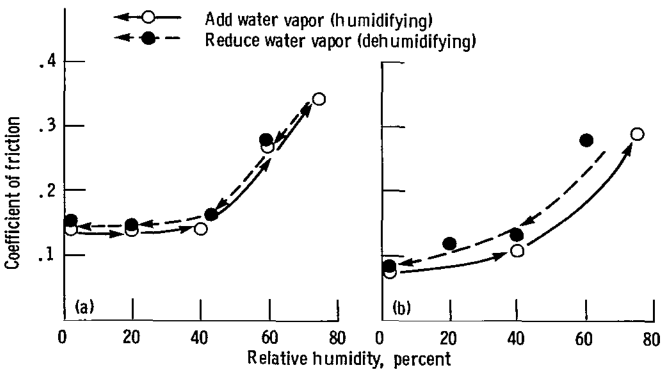
Single-pass sliding friction experiments were conducted with magnetic tapes in contact with polycrystalline nickel–zinc ferrite pins in both dry and humid nitrogen atmospheres. After placing the pin and tape into the experimental apparatus, dry nitrogen was admitted into the system (fig. 3(a)). The coefficient of friction measured for the tape was 0.14 in dry nitrogen at a load of 0.5 N (shown in fig. 8(a) with open symbols). The atmosphere was then humidified to the desired humidity (up to 78 percent) by admitting humid nitrogen into the system.

On humidifying the coefficient of friction remained low below 40-percent relative humidity. It increased rapidly with increasing relative humidity, as indicated by the open symbols in figure 8(a). On dehumidifying the coefficient of friction decreased rapidly between 78- and 40-percent relative humidities. It remained low below 40-percent relative humidity. The friction behavior of the tape as a function of relative humidity on dehumidifying is very similar to that on humidifying.

At the load of 0.25 N the results are consistent with those at the load of 0.5 N, as indicated in figure 8(b). The data in figures 4 and 8 indicate the significance of the water vapor effect in altering the friction behavior of tape surfaces in contact with nickel–zinc ferrite. The increase in friction is due to water vapor on the tape surface.

Frictional Response to Humidity Changes

A tape was preconditioned in dry nitrogen in the plastic box and maintained at that condition during the entire



(a) Normal load, 0.5 N.
(b) Normal load, 0.25 N.

Figure 8. – Effect of humidifying and dehumidifying on friction of magnetic tape in contact with nickel–zinc ferrite pin. Sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.

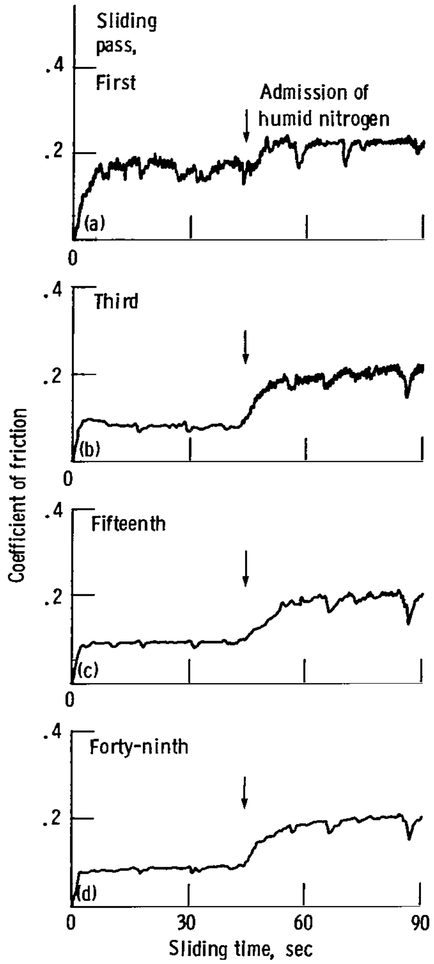


Figure 9. – Coefficient of friction as function of sliding time for magnetic tape sliding against nickel-zinc ferrite pin. Effect of humidity change due to admission of humid nitrogen. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.

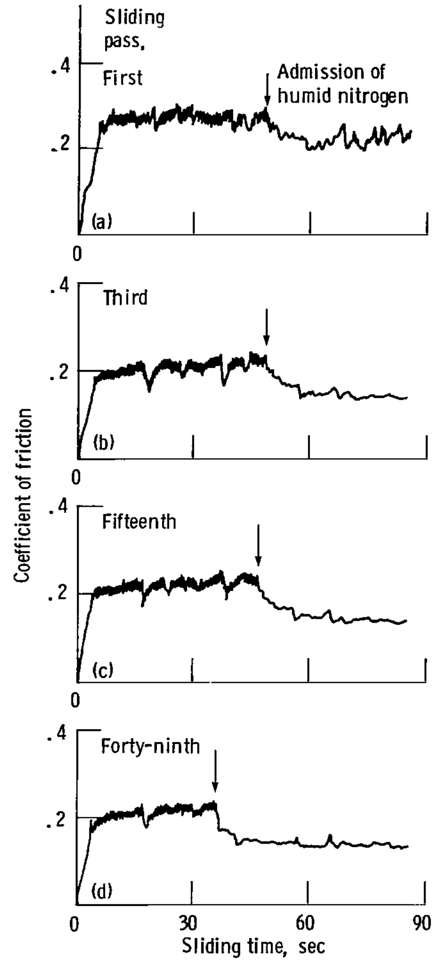


Figure 10. – Coefficient of friction as function of sliding time for magnetic tape sliding against nickel-zinc ferrite pin. Effect of admission of dry nitrogen. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen.

sliding friction experiment. After sliding for 40 sec in dry nitrogen, the vicinity around where the tape contacts the ferrite pin (less than 100 mm^2) was flooded with humid nitrogen having 61-percent relative humidity. Figure 9 presents coefficient of friction as a function of sliding time resulting from such environmental conditions. In the first pass, right after admitting humid nitrogen, the coefficient of friction increased. The coefficients of friction measured at the area flooded with humid nitrogen were 30 to 40 percent higher than those in dry nitrogen. With repeated sliding passes, the tape exhibits about 2 to 2½ times higher friction than in dry nitrogen, when local humidity was raised. This difference in humidity dependence for the single-pass and multipass sliding is possibly due to the change of the surface profile of tape with sliding.

A tape was preconditioned at 63-percent relative humidity in the plastic box and maintained at that condition during entire sliding friction experiments. The vicinity surrounding the tape-ferrite contact was flooded with dry nitrogen after sliding for 40 sec in the humid nitrogen atmosphere. Figure 10 presents a typical coefficient of friction as a function of sliding time. Another surprising aspect of humidity dependence is clearly seen in figure 10. When the contact area was flooded with dry nitrogen, the coefficient of friction is lowered dramatically. The tape, with the surface flooded with dry nitrogen, exhibited about 80 percent the friction in the single pass of sliding and 60 percent in the multipasses of sliding of that obtained in the humid nitrogen atmosphere.

Figure 11 presents a typical coefficient of friction as a function of sliding time for magnetic tape in contact with the nickel-zinc ferrite pin. The vicinity surrounding the tape contact with the pin had been flooded with dry nitrogen (fig. 3(b)). At approximately 30 sec of sliding time, the supply of dry nitrogen was stopped and then the humid nitrogen, at 61-percent relative humidity, was admitted to the contacting area for about 30 sec. After admitting humid nitrogen, the supply of humid nitrogen

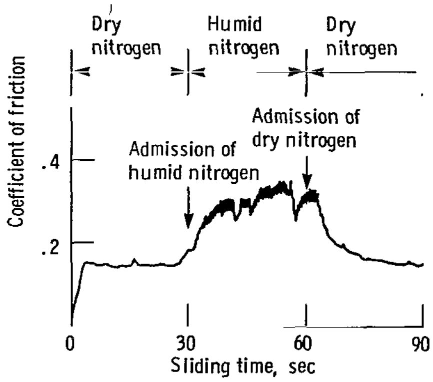


Figure 11. – Coefficient of friction as function of sliding time for magnetic tape sliding against nickel-zinc ferrite pin. Effect of humidity changes due to admission of humid or dry nitrogen. Normal load, 0.5 N; sliding velocity, 0.1 mm/sec; temperature, 23° C; environment, nitrogen; number of passes, 3.

was stopped and dry nitrogen was again allowed to flow into the contact area.

Figure 11 clearly indicates the marked increase in coefficient of friction as the humidity increases. It takes only a short transient time (around 10 sec) for the friction to decrease or increase in relation to the humidity changes.

Conclusions

As a result of the sliding friction experiments conducted with a magnetic tape in contact with a nickel-zinc ferrite spherical pin in dry and humid nitrogen, the following conclusions are drawn:

1. The coefficient of friction is strongly dependent on the ambient relative humidity. Although the coefficient of friction remained low below 40-percent relative humidity, it increased rapidly with increasing relative humidity above 60 percent.
2. The surface softening effect on the friction behavior of tape is clearly seen. The effect of friction as a function of relative humidity on dehumidifying is very similar to that on humidifying. The surface softening of the tape due to water vapor increases the friction of the tape.
3. The general ambient environment does not affect the friction behavior of the tape, if the area immediate to the surrounding tape-ferrite pin contact is flooded with controlled nitrogen. The response time for tape friction to change with humidity is of the order of only 10 sec.

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Lewis Research Center
Cleveland, Ohio, September 27, 1983

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16. Abstract

The effects of humidity of moist nitrogen on the friction and deformation behavior of magnetic tape in contact with a nickel-zinc ferrite spherical pin were studied. The results indicate that the coefficient of friction is markedly dependent on the ambient relative humidity. Although the coefficient of friction remains low below 40-percent relative humidity, it increases rapidly with increasing relative humidity above 40 percent. The general ambient environment of the tape does not have any effect on the friction behavior if the area where the tape is in sliding contact with the ferrite pin is flooded with controlled nitrogen. The response time for the friction of the tape to humidity changes is about 10 sec. The effect of friction as a function of relative humidity on dehumidifying is very similar to that on humidifying. A surface softening of the tape due to water vapor increases the friction of the tape.

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